Control Methods for Q20 Optics

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Introduction

Control of strong head-tail and electron cloud inestabilities

- Limiting factor in LHC/Injectors to maximize intensities and luminosity.
- Electron Cloud Instabilities (ECI) CERN is conducting an effort to coat critical parts of the accelerator with amorphous carbon. Wide band feedback is complementary.
- Transverse Mode Coupled Instabilities (TMCI) CERN redesigned the lattice for SPS (Q26 $\rightarrow$ Q20) to increase the beam current threshold to TMCI.
- Wide band feedback can control both instabilities.
- This technology opens new options Scrubbing at SPS and processing intrabunch signals for instrumentation and bunch diagnostic.

Introduction

Lattices and main parameters for SPS ring

- - Q26 Optics (actual lattice)
  - Bunch length = 3.2ns (4 σ_Z at 26 GeV/c)
  - Tunes: $Q_X = 26.13$, $Q_Y = 26.185$, $Q_X = 0.0059$
  - Fractional tunes: Y - $\omega_\beta = 0.185$, Z - $\omega_s = 0.0059$
- - Q20 Optics (new lattice)
  - Bunch length = 3 ns (4 σ_Z at 26 GeV/c)
  - Tunes: $Q_X = 20.13$, $Q_Y = 20.185$, $Q_X = 0.0170$
  - Fractional tunes: Y - $\omega_\beta = 0.185$, Z - $\omega_s = 0.0170$

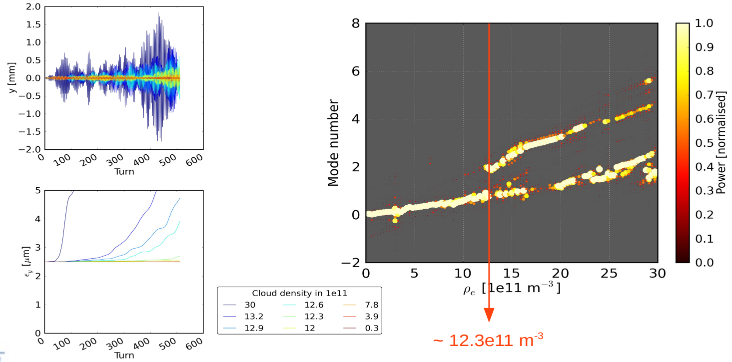
General Considerations of Q20 optics

Electron Cloud Instabilities (ECI)

-SPS Q20 Lattice - No feedback, scan electron cloud densities

- Mode 0: $\omega_\beta = 0.185$, Mode 1: $\omega_\beta + \omega_s = 0.202$ at $\rho_e = 0\text{m}^{-3}$, 26 GeV/c.

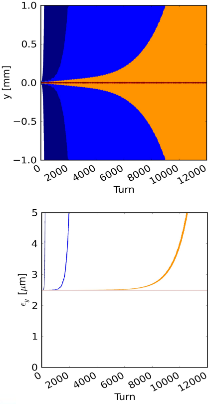
ρ_e = [1 – 30] x 1e11 m^{-3} (from red over green to blue)

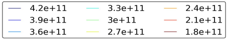


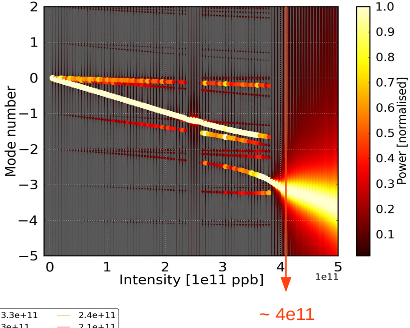
General Considerations of Q20 optics

Electron Cloud Instabilities (ECI)

-SPS Q20 Lattice - No feedback, scan for beam intensity
- Mode 0: $\omega_\beta = 0.185$, Mode -2 : $\omega_\beta - 2\omega_s = 0.151$ at $I_b = 0\text{mA}$, 26 GeV/c.







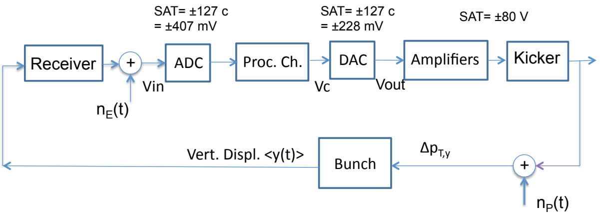
Controller Design

Control Requirements

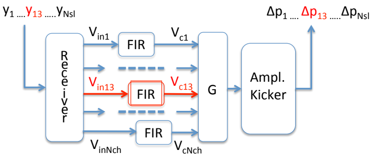
- - Stabilize the intra-bunch dynamics
    - Unstable modes for ECI -TMCI
    - Robust to parameter changes in the beam dynamics and different conditions (steady-state) of the machine
- - Maximum dynamic range to keep stability-performance for a maximum set of transient conditions
- - Feasible controller
    - Unstable dynamics sets the minimum gain in the controller
    - Intrisic delay sets the maximum gain in the controller
- - Reject noise and perturbations
    - Isolate vertical displacement signals from longitudinal/horizontal signals.

Controller Design

Control Configuration - Processing Channel



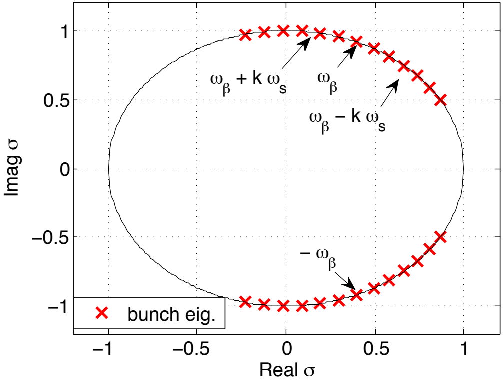
- 4 GSa/s digital channel. Flexible, reconfigurable processing
  - Analog equalization of pick-up and cable transfer functions.
  - 2 ADCs / 1 DAC
- Detail of processing channel
  - 16 samples across 5 ns bucket.
  - Finite impulse response (FIR) and Infinite impulse response (IIR) filters
  - Individual processing per sample



Controller Design

Dominant Bunch Dynamics

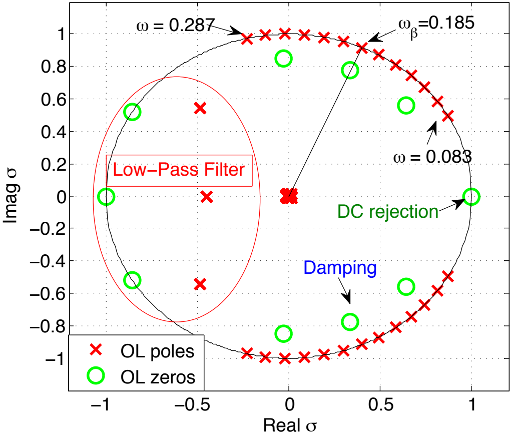
The bunch is characterized by the dominant modes whose eigenvalues are $\pm i(\omega_\beta + k\omega_s)_{k=\ldots-6,..0,\ldots+6,\ldots}$. In the fig. those eigenvalues are mapped in Z domain: $\sigma_k = e^{\pm i(\omega_\beta + k\omega_s)T_r}|_{k=-6,..0,\ldots+6}$



- Controller filter composed of different sections:
  1. DC rejection and phase adjustment
  2. Damping around dominant modes (phase adjustment)
  3. Low-pass filter

Controller Design

Filters



Filter pole-zeros

- DC rejection and phase adjustment
- Damping around dominant modes (phase adjustment)
- Low-pass filter

Controller Design

Filters

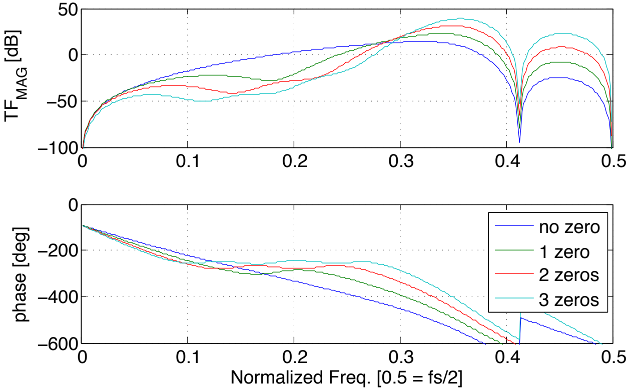


Figure: Transfer function of IIR filters

Evaluation of system parameters

System Stability - Noise

- Evaluate $\pm$ 6 lateral bands around the betatron frequency (Assume power stage has a ideal bandwidth 850-1000 MHz)
- Evaluate different filters with increasing number of zeros.
- Same low-pass order in all cases - Third order Chebyshev filter type II.
- Critical parameters: LP Bandwidth, position of zeros, overall phase adjustment.
- Criteria: Stability margins, Equivalent noise gain,
- Stability: use root locus (plots the position of the system eigenvalues for different gains in the controller, $G = 0, ..., G_{max}$)

Stability Analysis

IIR Filter - 1 zero

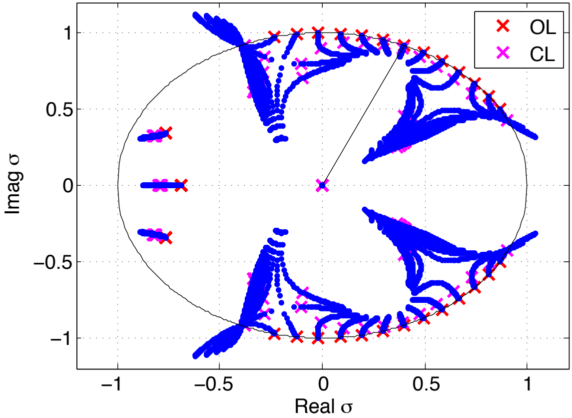


Figure: Complete Root Locus - IIR

Stability Analysis

IIR Filter - 1 zero

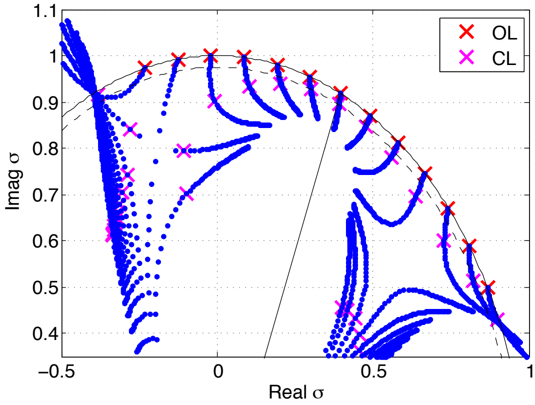


Figure: Detail Root Locus - IIR

Stability Analysis

IIR Filter - 2 zeros

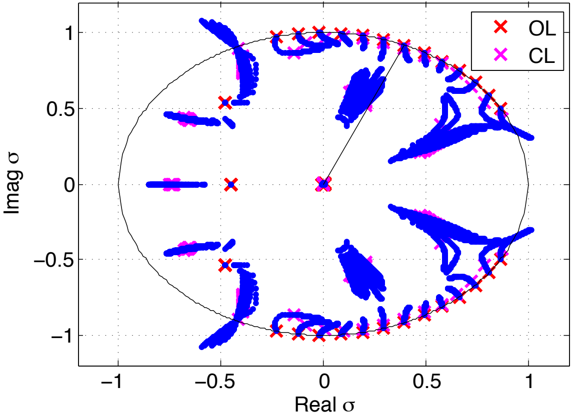


Figure: Complete Root Locus - IIR

Stability Analysis

IIR Filter - 2 zeros

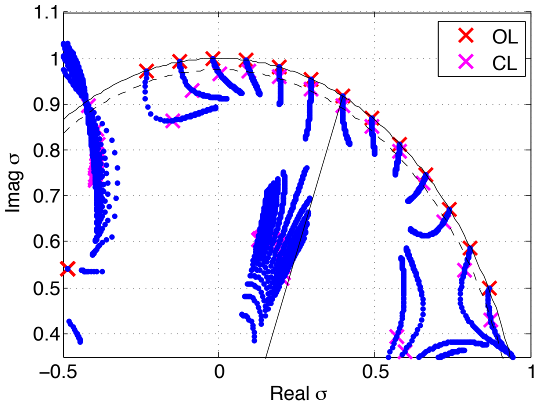


Figure: Detail Root Locus - IIR

Stability Analysis

IIR Filter - 3 zeros

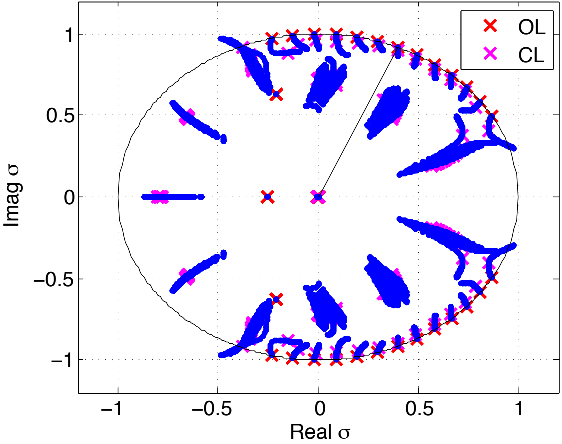


Figure: Complete Root Locus - IIR

Stability Analysis

IIR Filter - 3 zeros

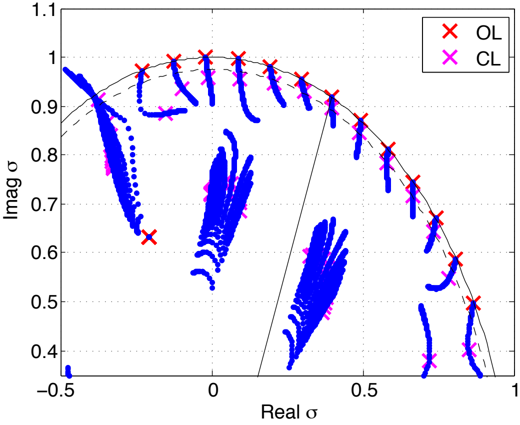


Figure: Detail Root Locus - IIR

Results

Noise

- IIR 1 zero: BW= 0.9, Gol = 0.4, Gf = 575
  $\sigma = 770$ (for $\sigma_{in} = 1$, $G_2 = 770$)
- IIR 2 zeros: BW= 0.8, Gol = 0.4 Gf = 639
  $\sigma = 588$ (for $\sigma_{in} = 1$, $G_2 = 588$)
- IIR 3 zeros: BW= 0.7, Gol = 0.7 Gf = 1086
  $\sigma = 543$ (for $\sigma_{in} = 1$, $G_2 = 543$)

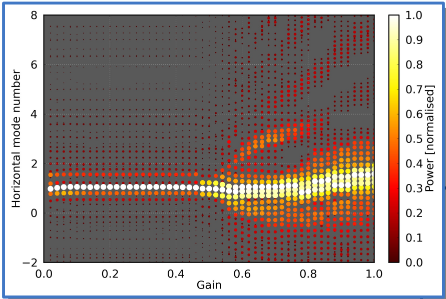
Work in Progress

Result Validation - Implementation

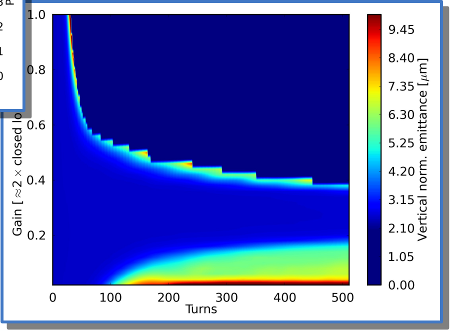
- Validate this preliminary design for the controller with analysis and results using macroparticle simulation codes.
- Define a more precise representation for the reduced model of the bunch
- Include in the feedback system realistic models of the hardware - Analyze limitations and partition of gain around the feedback loop.
- Define controller filter for Q20 optics and implement in FPGA.

Stability Analysis

Preliminary Results Head-Tail Simulations - Filter with 1 zero



- E-cloud density: 16e11
- Stabilising at gain 0.2
- Destabilising at gain 0.4

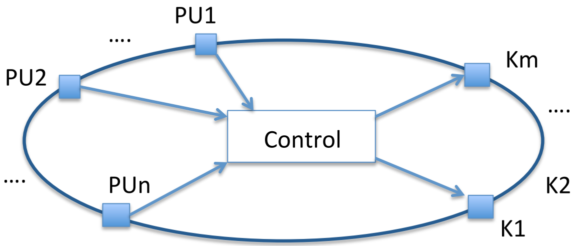


Kevin Li

Future considerations

Use of multiple pick-ups / kickers in the feedback system

To reduce the latency in the controller filter we start evaluating the use of multiple pick-ups and kickers distributed around the ring.
Adds flexibility and improves signal to noise.



Conclusions

- We started evaluating a design for the feedback controller for the SPS Q20 optics.
- It imposes a challenge due to the large synchrotron frequency, spreading out in a wide frequency band the dominating modes of the bunch.
- Multiple filters has been analyzed using as criteria system stability and noise gain of the filter.
- More work is necessary to validate this design before implementing it in the feedback firmware.
- Parallel studies are conducted to understand the benefits in this design of using multiple kickers / pick-ups distributed around the ring.